Experimental Investigation and Optimization of Parameters in Electrochemical Machining Operation

A thesis Submitted in partial fulfilment of the requirements for

the award of the degree of

Master of Technology

In

Mechanical Engineering (Production Engineering)

By

Pankaj Sahu

(213ME2416)

Under The Guidance of

Prof. K. P. Maity

Department of Mechanical Engineering

National Institute of Technology Rourkela

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CERTIFICATE

This is to certify that the thesis entitled — **Experimental Investigation and Optimization of Parameters in Electrochemical Machining Operation** submitted to the National Institute of Technology, Rourkela (Deemed University) by **Pankaj Sahu Roll No. 213ME2416** for the award of the Degree of **Master of Technology** in Mechanical Engineering with specialization in—**Production Engineering** is an Authentic work conceded out by him under my supervision and guidance. To the best of my knowledge, the results presented in this thesis has not been submitted to any other University or Institute for the award of any degree or diploma. The thesis, in my opinion, has reached the standards fulfilling the requirements for the award of the degree of Master of technology in accordance with regulations of the Institute.

Place: Rourkela

Date

Dr. K. P. Maity

Professor

Department of Mechanical Engineering

National Institute of Technology, Rourkela

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Date

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Abstract

Electrochemical Machining is a non-traditional machining process which is used to machine difficult-to-machine materials such as super alloys, Ti-alloys, stainless steel etc. The basic working principle is based on Faraday law of electrolysis due to which the material removal takes place atom by atom by the process of electrolysis. This experiment highlights features of the development of a comprehensive mathematical model for correlating the interactive and higher order influences of various machining parameters on the dominant machining criteria i.e. the material removal rate (MRR), surface roughness (SR) and overcut (OC) phenomenon through Response Surface Method (RSM) method using the pertinent experimental data as obtained by experiment.

The present work has been undertaken to find the material removal rate, surface roughness and overcut by electrochemical dissolution of an anodically polarized work piece (AISI304 stainless steel) with a copper electrode of hexagonal cross section. Experiments were conducted to analyse the influence of machining parameters such as feed rate, voltage and electrolyte concentration. Analysis of variance (ANOVA) is employed to indicate the level of significance of machining parameters. It is observed that concentration is the most significant factor for response of material removal rate and in case of surface roughness voltage is the most significant factor. For response of overcut, the voltage is most significant factor.

Keywords: Electrochemical Machining(ECM), Material removal rate, Surface roughness, Overcut, Response Surface Methodology.

Contents

List of Figures

List of Tables

Page no.

Chapter 1: Introduction

1.1 Overview of ECM Process

ECM is a non traditional machining process which is used to machine difficult to machine materials such as alloy steel, Ti alloys, super alloys and stainless steel etc. ECM is characterised as reversed electroplating process. In the year 1983, Faraday established the laws of electrolysis(electroplating). This is the basis for this process which is very very popular not only in the industries , but outside these industries also for some other purposes like for electroplating of different materials. ECM is a controlled anodic dissolution process in which a very high current is passed between the tool which is cathode and workpiece which is made anode, through a conductive fluid which is also called electrolyte. It is a non contact process in which the cavity obtained is the replica of the tool shape.

In ECM workpiece is dipped in a working fluid also called the electrolyte and electrolyte continuously flows through the inter electrode gap between the anode and the cathode. When power supply is switched on, removal of material takes place from work and ions are washed away by flowing electrolyte solution. Metal hydroxide ions are formed by the ions which by centrifugal separation are removed from the conductive electrolyte solution. ECM process is found advantageous particularly for high strength super alloys. ECM is an important process for semiconductor devices and thin metallic films because a basic requirement of semiconductor industry is the machining of components of criticle shape and high strength alloys. This process is also used for shaping and finishing operation in aerospace and electronic industries for different parts of the opening. Basic schematic diagram & inter electrode gap is shown in the figure 1.1.

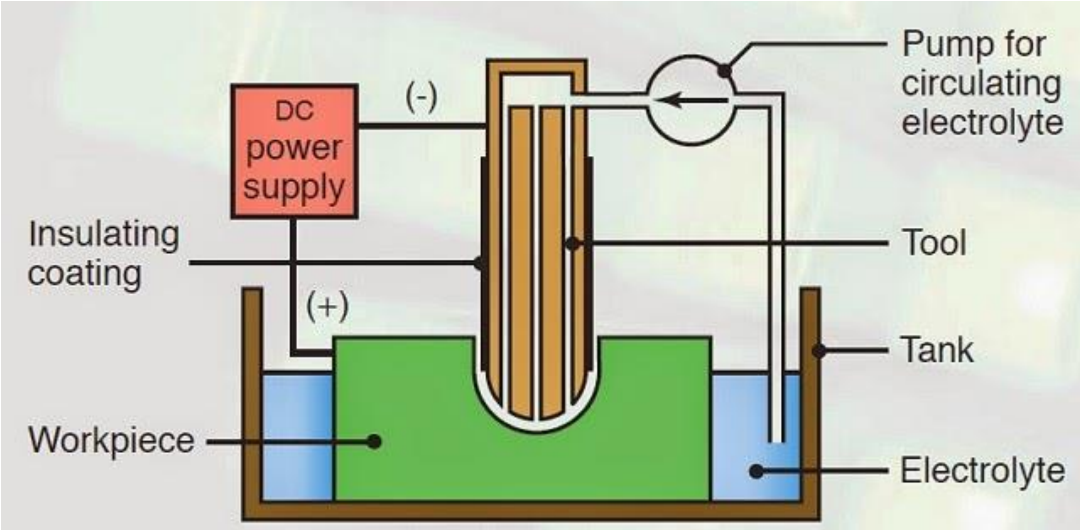


Figure 1.1 : Basic schematic diagram of the ECM process[33]

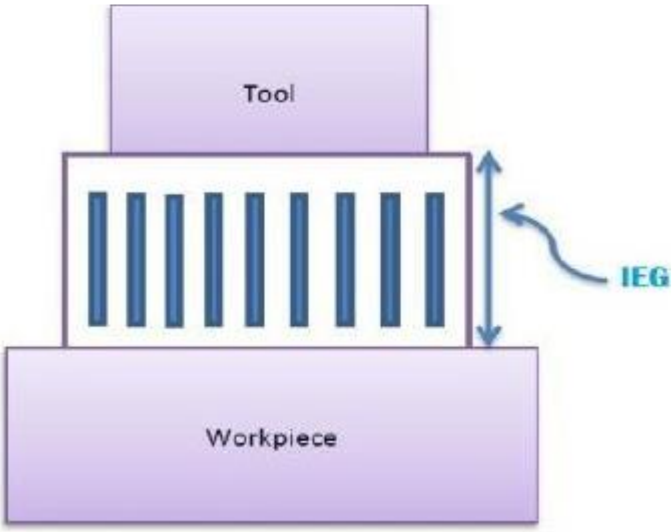


Figure 1.2 : The inter electrode gap[31]

Tool is connected to the negative terminal of DC power supply and the workpiece is connected to the positive end of power supply and a very high current at low voltage will be supplied or passed through this gap. Since high current is used generally, the electrode and the workpiece both will be insulated from the system so that there is no shot circuiting or leakage of the current does take place and as far as possible the electrolyte will be filtered and kept on flowing through the electrodes continuously. This rate of pumping and the the pressure at which this electrolyte will be pumped should be decided before hand depending on the applications or requirement of the process. Therefore, the pump for flowing or pumping this electrolyte should be decided accordingly.

1.2 Working principle of ECM

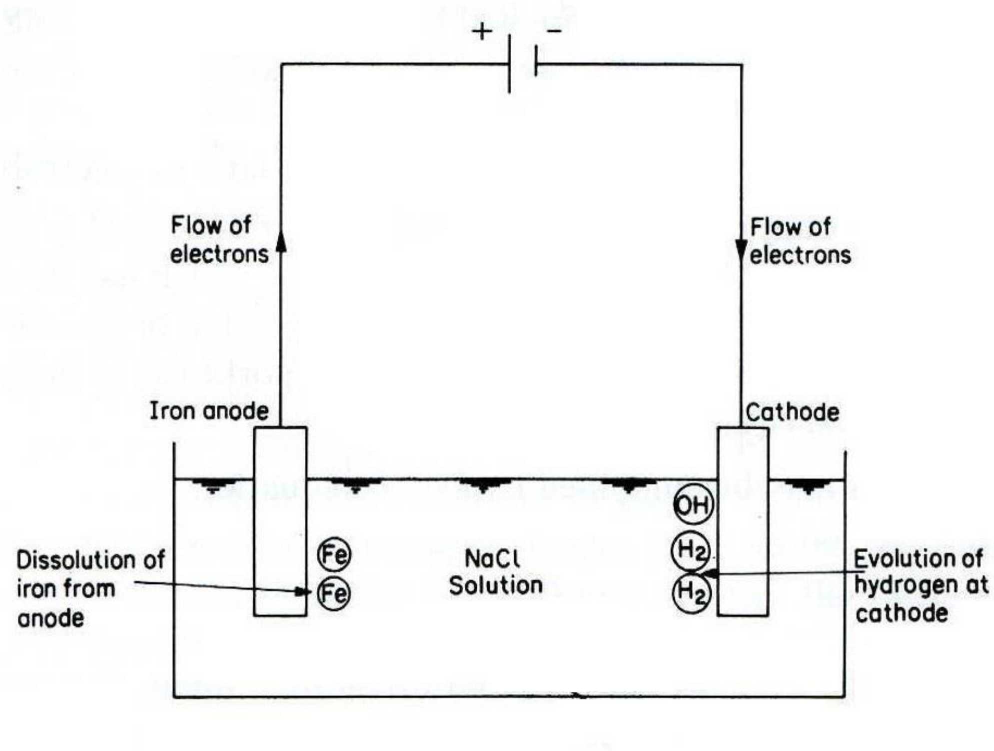


Figure 1.3: Working principle of ECM[33]

Electrolysis process is the basis of ECM. Electrolysis as the name suggests is a chemical phenomenon which occurs between two conductors dipped in a electrolytic solution and electric current is passed between them. For example, if one iron rod and copper wire are dipped in a Sodium Chloride solution and as shown figure 1.3 they are connected to a source of direct current, the basic ECM cell will be formed. The ECM tool is positioned very close to the work piece which are dipped or partially into electrolyte solution. They are then connected to electrical energy source which is a DC source. The entire system of electrolyte and electrodes is called electrolytic cell. The positive terminal will be connected to the workpiece because it is an anodic dissolution process, from which the material will go into the solution whereas the plate or electrode is connected to negative terminal in which metal will get deposited. The electrolyte is kept on flowing in between as we have already indicated leaving a gap between the workpiece and the tool. It means geometry of the tool that we can use has no constraint. The tool can have different shapes as per the requirement. It can be of any shape as per the requirement of the workpiece and therefore, the same shape will be replicated or reproduced on the workpiece. The control system will maintain inter electrode gap at a particular rate either for the tool advancement or the work piece advancement. The material which come into the solution will be taken away before getting deposited on the electrode so that the electrode geometry or the c/s donot change. The electrolyte flows through the space between the two electrodes to remove the products produced during machining. The material removal rate from the anode is inversely proportional to the gap between the two electrodes. There is a simultaneous movement of the cathode towards anode to maintain this gap as the machining proceeds. The selection of electrode material is very very important. So, there should be a parity between the electrolyte used and the electrodes used. The chemical reactions occurring at the cathode and anode are called as cathodic and anodic reactions respectively.

Some important points about the ECM process:

- In electrolytes, the atoms or group of atoms carries the current and not by the electrons as in the case of conductors, when the electrons move and as a result we get current.
- The atoms have acquired positive or negative charges by either lost or gained electrons and such atoms are called ions.
- The ions that carry positive charge are attracted by the cathode and they move in the direction of the positive current through electrolyte and are referred to as cations. The negatively charged ions get attracted to the positive electrode i.e. the anode and they are referred to as the anions.

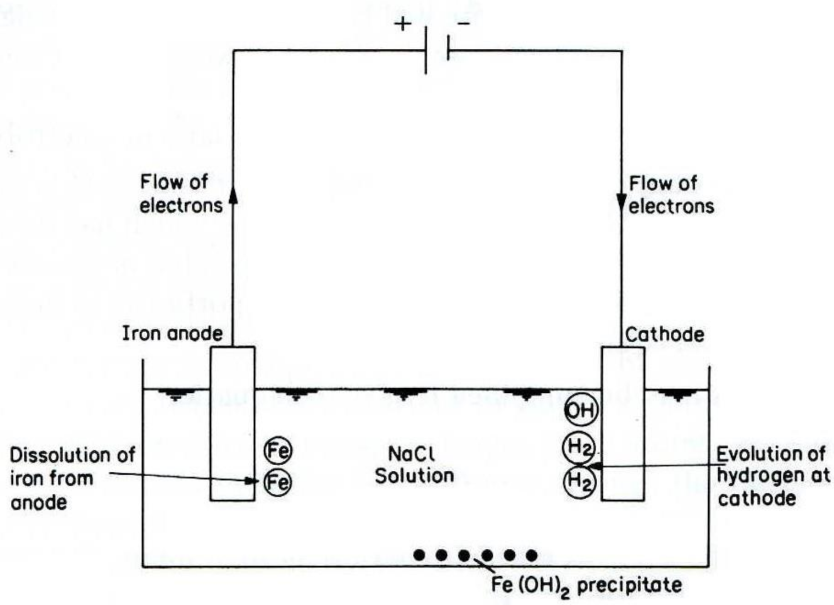


Figure 1.4: $Fe(OH)_3$ precipitate at the bottom[33]

In the above figure there is an electrochemical cell in which iron anode and cathodes are used, dipped partially in the solution of common salt that is sodium chloride solution which acts as the electrolyte. The cell is connected to one energy source and iron is connected to the positive terminal. In this external circuit the flow of electron is from iron anode to cathode. However, in the solution there are flow of ions that is the iron from this anode goes into the solution in the form of ions and they react with this solution and forms ferric hydroxide which gets precipitated as shown in the figure 1.4. And on the cathode water gets dissociated into OH^- ions and H^+ ions. Hydrogen gas bubbles are evolved and they goes away. And then the current flows in the form of ions, positive ions from anode and negative ions from this cathode. Negative ions from cathode will be attracted towards positive anode. Whereas the positive ions from anode will be attracted towards cathode and the hydrogen gas will be evolved.

1.3 Theory of ECM

The basic chemical reactions taking place for say NaCl as electrolyte and Iron as workpiece are

$$NaCl \longrightarrow Na^{+} + Cl^{-}$$

$$H_2 \longrightarrow H^{+} + OH^{-}$$

Hydrogen ions (H+) forms hydrogen gas by taking away electrons from the cathode (tool)

$$2H^{+} + 2e^{-} \longrightarrow H_2\uparrow \text{ at cathode}$$

Similarly, the iron atoms come out of anode (workpiece) as

$$Fe \longrightarrow Fe^{++} + 2e^{-}$$

Within the electrolyte iron chloride is formed when iron ions combine with chloride ions and sodium hydroxide is formed when sodium ions combine with hydroxyl ions.

$$Na^{+} + OH^{-} \longrightarrow NaOH$$

$$Fe^{++} + 2OH^{-} \longrightarrow Fe(OH)_2\uparrow$$

And iron ions will combine with negatively charged hydroxyl ions to form ferric hydroxide.

$$Fe^{++} + 2Cl^{-} \longrightarrow FeCl_2\downarrow$$

Similarly, chlorine ions that is present in the sodium chloride solution as part of the disassociation of sodium chloride in the solution will form ferric chloride with iron ions which are positively charged. This Ferric chloride will also get precipitated as in the case of ferric hydroxide.

Hence, in practice $FeCl_2$ and $Fe(OH)_2$ are formed and get precipitated. Hence in practice, $FeCl_2$ and $Fe(OH)_2$ are formed and get precipitated in the form of sludge and the workpiece gets gradually machined due to atomic level dissociation.

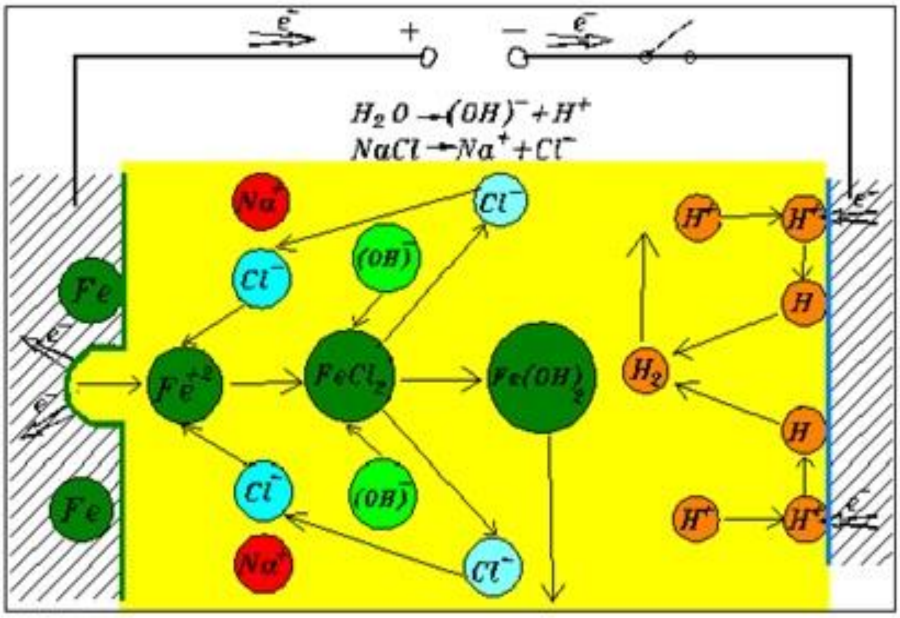


Figure 1.5 : Electrochemical reactions during ECM of iron in NaCl Electrolyte[31]

Reactions at the anode as shown in the Figure 1.5 is demonstrated as follows,

$$Fe \longrightarrow Fe^{++} + 2e^-$$

$$Fe^{++} + 2Cl \longrightarrow FeCl_2$$

$$Fe^{++} + 2OH^- \longrightarrow Fe(OH)_2$$

$$FeCl_2 + 2OH^- \longrightarrow Fe(OH)_2 + 2Cl^-$$

$$2Cl^- \longrightarrow Cl_2\uparrow + 2e-$$

$$2FeCl_2 + Cl_2 \longrightarrow 2FeCl_3\downarrow$$

$$H^+ + Cl^- \longrightarrow HCl$$

$$2Fe(OH)_2 + H_2 + O_2 \longrightarrow 2Fe(OH)_3\downarrow$$

$$Fe(OH)_3 + 3HCl \longrightarrow FeCl_3$$

$$FeCl_3 + 3NaOH \longrightarrow Fe(OH)_3\downarrow + 3NaCl$$

Reactions at the cathode is given below,

$$Na^{+} + e^{-} \longrightarrow Na$$

$$Na + H_2O \longrightarrow NaOH + H^{+}\uparrow$$

$$2H^{++} + 2e^{-} \longrightarrow H2\uparrow$$

There will be no deposition at cathode and only Hydrogen gas will evolve.

1.4 Classification of ECM process

1.4.1 Electrochemical Turning Process

One of the special application of ECM is ECT. For electrolytic machining of rotating workpiece the standards or principles of ECM can be used. Peripheral cuts and face cuts can be accomplished by the process of ECT. ECT employs a non contacting tool and all metal removal takes place by electrolytic activity. In EMM electrolyte is flooded over the workpiece to soften it prior to mechanical material removal by traditional tools. Application of ECT is in the large disk forgings. Full-face electrodes, in some cases are plunged into a rotating disk. Races of bearing can be finished with close tolerances and with surface roughness less than 0.13 μ m. It has another application in turning of AISI316 workpiece, using electrolyte of NaCl and NaNO3 to a surface finish of less than 0.25 μ m. There is a similarity of operating parameters material removal rate and tolerances with that of ECM. Tolerance holding capability is usually in between 0.038-0.08 mm. Under unsual condition, tolerances can be held to ±0.03mm; and in rate cases, tolerances can be held to ±0.013 mm.

1.4.2 Electrochemical Wire Cutting

In this process of machining a metal wire is used as cathode and workpiece as anode. The workpiece can be designed by relative movement stuck between workpiece and steel wire. This process is very much similar to wire EDM. Process is best suited for fine drilling and one or two direction cutting. Rectangular wire is more suitable than circular wire in this process. Compared with conventional ECM this process has a restricted feed rate. Feed rate is reliant on diameter of workpiece and width of wire. This process is suitable for superfinishing with higher surface finish 0.15µm. This methodology is exceptionally suitable with little workpiece measurement. Surface finish is preferred for level surface over cylindrical. The tooling system is cheap and force ingestion is low. Parameters like worpiece relation speed, feed rate and electrolyte flow rate influence Ra.

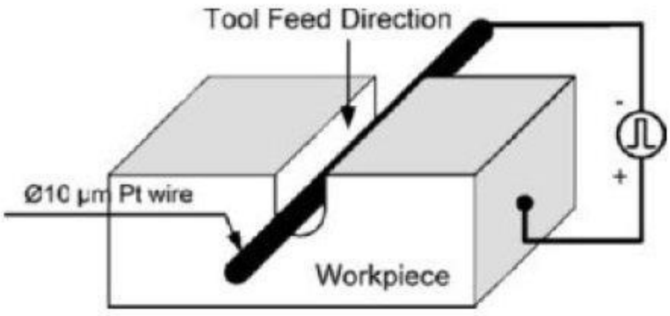


Figure 1.6 : Schematic of wire-ECM[31]

1.4.3 Electrochemical Grinding Process

Electrochemical Grinding is a variety of ECM that consolidates electrolytic movement with the physical evacuation of material by use of charged grinding wheels. It can deliver burr and stretch free parts without any metallurgical harm brought on by grinding, wiping out the need for secondry machining operations. Similar to ECM, ECG creates no heat to contort fragile segments. It can handle any electrochemically reactive material. The most well-known reason clients pick ECG is for the burr free nature of cut.

In the event that a part is troublesome or expensive to deburr, then ECG is the best alternative. Materials which are hard to machine by traditional methods, that are liable to heat damage are likewise great candidates for no heat and stress free characteristics of ECG. The stress free cutting abilities of the methodology additionally make it perfect for thin wall and sensitive parts. The real value of ECG is in metalworking applications that are as well troublesome or time intensive for conventional mechanical systems (deburring, grinding, turning, milling and so on). When compared with non-traditional machining methods such as wire and sinker EDM it is more effective. ECG is quite often more savvy than EDM. The tolerance that can be attained to utilizing ECG depend significantly on the material being cut, the size and profundity of cut and utilizes ECG parameters. On small cuts, tolerance of (0.005mm) can be attained to with cautious controlling of grinding parameters.

1.4.4 Electrochemical Drilling Process

Electrochemical drilling (ECD) proves to be useful system for processing very small holes on numerous difficult to-machine metals, and is also a decent process for pack drilling. The electrolyte stream of ECD process can be characterized into two types, forward stream and backward stream. During the ECD process with forward stream, the electrolyte radially spreads out from the middle gap of the cathode in rapid expansion and divergence which causes phenomenon of flow field disturbing. The disturbing phenomena would decline machining method stability. The most normal approach to reduce stream field disturbing is to apply the converse electrolyte stream, in which under the pump power electrolyte crossing interelectrode gap was thrown out from the inlet of the electrode tube to the electrolyte tank. But, sealing of fine dynamic in customary reverse flow to shape an encased space in the electrolyte cell is troublesome and convoluted particularly for multiple terminals. In this exploration, the reverse stream is attained to in the method for electrolyte-extraction without element fixing. Electrolyte released in the machining region needs just to be exposed to the barometrical air. The possibility of usage of reverse flow was significantly improved.

While machining multiple holes, the non-uniform of electrolyte supply will bring about diverse machining status for each opening. This would result in short circuit. The stream conveyance along the electrode is found by the construct of combining manifold, and the principle parameters of the complex are contemplated and upgraded consequently.

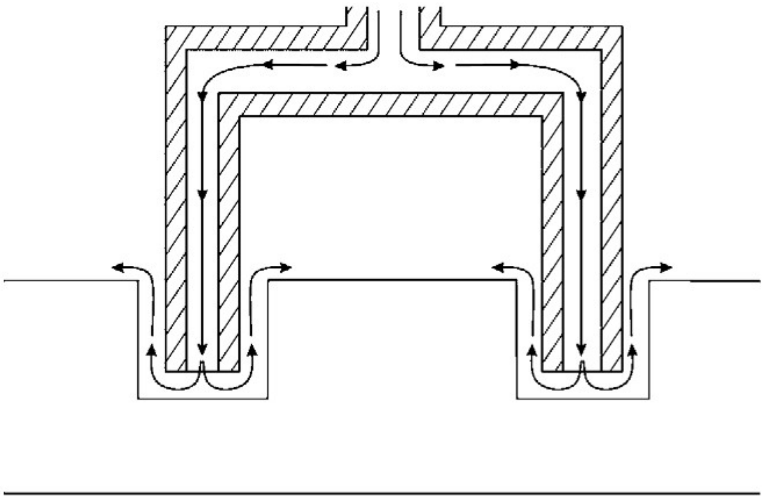


Figure 1.7 : Electrochemical trepanning[30]

1.4.5 Electrochemical Honing Process

It is a standout amongst all the potential micro machining processes in which material removal takes place by anodic dissociation along with mechanical abrasion of bonded rough grains of abrasive.

The exactness of gears by ECH is a long tool life, high accuracy and productive gear finishing methodology. Electrochemical honing method can be utilized to increase the metal removal rate by a variable of 2 or 3 than that attained to in traditional honing. Traditional abrasive sharpening stones are utilized to keep up the exact size of the bore. A current density of the order 15-45 A/cm2 at 6-30v dc is supplied to the work piece and anodes mounted between the stones and fitted with spacers so that there is a gap of around 0.15 mm between the work and the anode. The electrolyte is supplied under pressure of 5-10 kg/cm2. Traditional and electrolytic metal removal happens at the same time. The reciprocating and and turning movement of the apparatus guarantees an exactness of ±0.002 mm. A surface finish of 0.05μm can be effortlessly accomplished easily. The advantage of this procedure are increased metal removal rate, burr free action, less pressure needed in the middle of stones and work, reduced noise, and diminished distortion in flimsy walled parts. ECH hardware is accessible more often than not for internal honing application

1.5 ECM machine Structure

Electrochemical Machining is the controlled removal of metal by anodic disintegration in an electrolytic cell. The electrolyte solution is forced through the gap between the tool and the work piece, while DC is supplied through the cell.

An ECM machine be comprised of a machine structure to locate and providefor the drive of the tool, an electrolyte framework and an electric power supply unit. However there are a several required attributes which every machine ought to express. The qualities are laid out below:

Steady feed drive: The feed drive framework to the system ought to be precise and consistent even at small feed rates. It should not stick-slip under by high forces.

Manageable work tank: For loading and unloading of work-pieces as well as for instrument setting the machine operational area should be effortlessly manageable. An attachment must be provided to prevent flopping of electrolyte.

Electrolyte Solution: The electrolyte is crucial for the process of electrolysis to work. It current and removes the sludge in addition to taking away the heat generated in the cutting region. The solution is pumped at around 14kg/cm^2 and at velocity of 30 m/s keeping in mind the end goal to always replenish the solution, which should never be permitted to reach boiling point as it would irritate the flow of current.

Stiffness: The machine ought to have structural rigidity to care the work-piece and tooling and repulse the hydrostatic and hydrodynamic forces delivered by electrolyte pressure.

Power supply: Conversion of available AC power to DC by means of rectifiers is the main purpose of power supply.To overcome the resistance at the gap, current of the order 1000-45000 amp is generally required and 5-25V is generally applied.

Erosion resistance: The machine base, work table and all the pertinent constituents ought to be made of corrosion resistant materials, for example, stainless steel, fiber glass, plastic, concrete or granite.

1.6 ECM machine parameters

1.6.1 Tool Feed Rate

In ECM procedure gap around 0.01 to 0.07 mm is maintained between the tool and work piece. The electrical resistance is small for small gap between the tool and work and maximum current and therefore maximum material will be removed. Depending on how quickly the metal has to be removed, tool is fed towards work.

1.6.2 Material Removal Rate

Electrolysis is the basis of material evacuation. Faraday proposed two laws for this, initial one is "the chemical change created by an electric current, which is the measure of any material dissolved or deposited, is directly proportional to amount of current supplied". Second is "The amount of different constituents dissolved by the same amount of electricity are proportional to their chemical equivalent weights ". MRR is a function of feed rate. A steady spacing between the tool and the work is in this manner establised. The real advantages of the metal removal rate procedure are that they don't bring about certain undesirable surface impacts which emerged in traditional machining processes. The main advantages are that they are stress free machining, burr free surfaces, reduced tool wear and cancelation of thermal damage to the work-piece. These methodologies have no impact on mechanical properties, for example, yield strength, ultimate strength, hardness, ductility etc.

1.6.3 Surface Finish

ECM can deliver surface finish of 0.45 µm by turning of tool or work. Any imperfection on tool face produce replica on work piece. tool surface therefore in this manner be polished. The finish is better in harder material. For ideal surface finish, careful electrode design, maximum feed rate, and surface improving additives in electrolyte are chosen. Low voltage reduces the equilibrium interelectrode gap and result in better surface finish and tolerance control. Low electrolyte concentration results in reduced machining gap and better surface finish. Low electrolytic temperature additionally improves surface finish.

1.6.4 Electrolyte and its concentration

The electrolyte solution is essential for the electrolysis process to work. An electrolyte in ECM performs three basic functions, which are as follows;

(1) Completing the electrical circuit and allowing the large current to pass.

(2) Sustaining the required electrochemical reactions,

(3) Takes away the heat generated and the sludge.

Electrical conductivity of the electrolytes must be high, toxicity and corrosiveness should be low.

The electrolyte pumping pressure is nearly 14 kg/cm^2 and at speed should not be less than 30 m/s.

Table 1.1 : Type of electrolytes[31]

S. No.	Alloy	Electrolyte
1	Iron based	Chloride solutions in water (mostly 20% NaCl)
2	Ni based	HCL or mixture of brine and H_2SO_4
3	Ti based	10% hydrofluoric acid + 10% HCL +10% HNO3
4	Co-Cr-W based	NaCl
5	WC based	Strong alkaline solution

1.6.5 Temperature control

The electrolyte conductivity fluctuates with variation in temperature, hence it must be held reasonably constant, otherwise the equilibrium machining gap will change. Low electrolyte temperature will bring about low metal evacuation rate. High temperature prompts overcut and vaporization of the electrolyte. It is kept up around (25-60)^{O}C.

1.6.6 Tool design

Any good conductor can be satisfactorily used as tool material because there is negligible tool wear in ECM process. But it must have sufficient strength to withstand the hydrostatic force, brought on by electrolyte when it is discharged at high velocity through the hole in the middle of tool and work. In order to allow electrolyte to pass along the bore in the tool the tool is made hollow for drilling holes.

Most commonly used tool material is copper. Some materials like graphite, brass and copper-tungsten are used since they have capability of nachining and non corrosive properties.

The main feature of tool design:

1. Defining the tool profile such that the preferred shape of the job is achieved for the certain machining conditions.
2. Designing the tool for concerns other than e.g. electrolyte flow, insulation, power and fixing arrangements.

1.6.7 Current

In ECM, current plays a vital role. The material removal rate is directly proportional to the current (i.e. higher is current, more will be material removal rate). Generally, this increase is observed up to a certain value and when current exceed beyond this level it negatively affects finishing and accuracy of work piece.

1.6.8 Servo system:

The main function of the servo system is to control the tool movement with respect to the work piece to follow the preferred path. It likewise controls the gap width in such an extent, that the discharge procedure can continue. In case the anode moves too fast and touches the work piece, short circuit happens. Since the voltage drop between the electrode is small and the current is constrained by the generator, short circuit contribute very little to material removal.

If tool feed is small, the gap widens and electrical discharge never happens. Another function of servo framework is to withdraw the tool anode during deterioration of gap.

Chapter 2 : Literature Survey

2.1 Overview on MRR and effect of parameters on MRR

B. Bhattacharyya et.al [6] has reported that the electrochemical micro machining as it offers numerous advantages, seems to be promising as a future micro-machining method. A suitable micro tool vibration framework is created, which comprises of micro tool vibrating unit, micro tool vibrating unit, etc. The framework developed was utilized sffectively to control MRR and accuracy of machining to meet small scale machining prerequisites. Micro-holes were created on thin copper workpiece by EMM using micro tool of stainless-steel. Trials have been completed out to estimate the process parameters for example electrolyte concentration, amplitude and micro-tool vibration frequency for creating micro-hole with high exactness and calculable measure of MRR.

Joao Cirilo da Silva Neto et.al [2] demonstrates an investigation of of the intervening parameters in ECM. The parameters studied in this papaer are material removal rate (MRR), over-cut and hardness. Four parameters were changed amid the experiments: flow rate of electrolyte, feed rate, voltage and electrolyte. Two solutions of electrolyte were used: sodium nitrate ($NaNO_3$) and sodium chloride (NaCl). The results demonstrate that feed rate was the principal parameter influencing MRR.

S K Mukherjee et.al [3] talks about role of NaCl in process of carrying current in electrochemical machining of iron work piece. Over-voltage-computed regarding equilibrium gap and penetration rate, demonstrates that only a small range of penetration rate and equilibrium gap are allowable.

K. P. Rajurkar et.al [4] examined the important advantages of the ECM procedure, for example, high MRR, damage-free and smooth machined surface, are regularly counterbalanced by the poor control of dimension. This paper based on the fundamental ECM dynamics presents a model of controlling ECM that accounts for the dynamic nature of the ECM process. The approach of state space is used to change it into the control model appropiate to a ECM control system based on a digital computer. The simulations were made for checking of model and controller configuration.

S.K. Mukherjee et.al [5] characterized that MRR of aluminum work piece has been calculated by ECM utilizing NaCl electrolyte at various current densities, also compared with the theoretical values. It is also concluded that resistance offered by electrolyte arrangement decreases sharply with expanding current densities, and simultaneously the over-voltage of framework first increases and afterwords achieves a saturation value with expanding current densities.

V.K. Jain et.al [6] has reported that electrochemical spark machining method has been effectively used for cutting quartz utilizing a controlled feed and a wedge edged tool. In ECSMWRP, deep cavity on the anode (as a tool) and work piece interface is formed in view of substance response. The cutting is possible regardless of the possibility that we make small size auxiliary electrode.

K.L. Bhondwe et.al [7] in this paper endeavors to build up a thermal model for calculating MRR in ECSM process. To begin with, temperature profile inside zone of influence of single spark is acquired with the utilization of FEM. The nodal temperature plays an essential role in finding MRR. The created thermal model based on FEM is discovered to be in the range of accuracy with the trial results. The increment in MRR increases with increase in electrolyte concentration.

R V Rao et.al [10] talked about the estimations of critical process parameters of ECM methods such as feed rate, flow velocity of electrolyte, and voltage play a important role in improving the measures of process performance. These incorporate dimensional accuracy, MRR, machining cost and tool life. A particle optimization algorithm is exhibited to locate the optimal combination of process parameters for ECM process.

2.2 Overview of Tool Design

Yuming Zhou et.al [12] discussed about the prior techniques for tool design in ECM. In this paper, actually create and test another way to deal with this issue which controls these troubles by utilizing a FEM inside an optimization formulation.

Jerzy Kozak et.al [13] investigated about the hypothetical and trial examinations of the relationship between the characteristic shape measurements imported upon the work piece surface by the micro-features of the tool electrode under given machining conditions. This work incorporated the investigation of electrochemical insulating groove features, copying of grooves and slots mini-holes. Restricting cases of micro-ECM are considered for duplicating and micro-shaping utilizing non-profiled tool cathodes.

K.P. Rajurkar et.al [14] had demonstrated that ECM method now progressively used in other commercial enterprises where coponents with hard-to-cut materials and criticle shape are needed. The most recent developments are examined, and primary issues in ECM improvement and related exploration have been raised. Improvements in designing of tool, micro-shaping, finishing, pulse current, numerically controlled and hybrid processes.

J.A. Westley et.al [15] examined about the steady electrolyte flow. This paper tries to recognize the elements, for example, insulation prerequisites that can identify with other parts of ECM. These perceptions would then be utilized while creating ECM electrodes. Work has been done in this paper by taking new cathodes for removing casting gate.

Chunhua Sun et.al [16] highlighted about the precise forecast of tool shape for ECM. It proposes a methodology utilising FEM for designing tool in ECM. This process is able to draw 3-D freestyle surface tool from the scanned information of known work piece.

2.3 Overview on micro-ECM

H. Hocheng et.al [17] reported about the methods to produce a hole of hundreds of micrometers on the surface of metal. It additionally talks about the effect of variables such as molar concentration and time of electrolysis, voltage and electrode gap upon the measure of MRR and dia of hole made. Results show the MRR increases with increasing molar concentration of electrolyte, electrical voltage.

Anjali V. Kulkarni et.al [18] talked about the present patterns and methods utilized for micro fabrication of parts. This paper tries to make a reasonable, fast micro fabrication and cost effective method. Focused on utilisation of ECS for layered manufacturing in micron.

S. K. Mukherjee et.al [19] described about the Material removal rate in ECM process by utilizing conductivity and over voltage of the electrolyte arrangement. It is found that over voltage plays an significant role than feed rate and IEG. MRR drops as over voltage increases and current efficiency decreases, which is directly related to the electrical conductivity of the electrolytic solution.

A. K. M. De Silva et.al [20] talked about the Electrochemical machining (ECM), which is used to attain surface finish 0.03ms µRa and accuracy better than 5 µm by utilizing pulsed power of comparatively short durations (1 - 10 µs) and small IEG (10 – 50 µm). The small IEG make the process significantly criticle than ordinary ECM.

K.L. Bhondwe et.al [21] wrote about the ECSM and EDM. It shows like ECM and EDM, ECSM is prepared to do machining of electrically non-conducting materials. This paper effort to build a thermal model for the evaluation of MRR by utilizing ECS. The created thermal model based on FEM is discovered to be suitable for this test result. The increment in MRR increases when concentration of electrolyte increases because of ECSM of soda lime glass work piece.

Mohan Sen et.al [22] examined that the Electrochemical machining methods produce for drilling micro- and macro-holes of smooth surface and reasonably satisfactory taper in various industrial applications especially in aerospace and computer industry

B. H. Kim et.al [23] examined about the Micro electrochemical machining (ECM) utilizing ultra short pulses. 0.1 M sulfuric acid was utilized as electrolyte and 3D micro structures were machined in stainless steel workpeice. It is shown how to avoid taper, by utilizing a disk-type electrode. To enhance productivity, multiple electrodes were connected and multiple structures were machined at the same time since the wear over tool electrode is irrelevent in ECM.

Se Hyun Ahna et.al [27] examined about the uncommon use of Electro-chemical machining in micro machining on the grounds that the electric field is not localized. In this work, to localize dissolution zone ultra short pulses with tens of nanosecond duration are used. The effects of pulse duration, voltage and pulse frequency on the localization distance were measured. 8 μm diameter high quality micro hole was drilled on workpiece of 304 stainless steel foil with 20 μm thickness.

2.4 Objective of present work

The objective of present work is to optimize the material removal rate (MRR), surface roughness (Ra) and overcut (OC) for the stainless steel (AISI304) with a Cu electrode. The experiments have been conducted using response surface methodology. The work piece material is AISI 304 SS and the selected machining parameters for study are feed rate, voltage and electrolyte concentration. In my work flow rate of electrolyte, the current across the work electrodes and electrolyte conductivity is kept constant.

Chapter 3 : Experimentation

In this chapter we will study about the experimental work which comprises of experimental set up, design of electrode, selection of work piece material, preparation of electrolytic solution and RSM method for stainless steel (AISI 304) specimen. By taking all this information in account we will calculate the material removal rate. Total 20 experimental runs have been done for RSM design and MRR and surface roughness was measured.

3.1 Experimental set up

The experiments the have been carried out on ECM set up supplied by Metatech-Industry, Pune which is having Supply of - 415 v +/- 10%, 3 phase AC, 50 HZ. And consist of three major sub systems which are being discussed in this chapter.

3.1.1 Machining Cell

This electro-mechanical assembly is a tough structure, connected with precision machined segments, servo mechanized vertical up / down motion of tool, an electrolyte dispensing course of action, illuminated machining chamber with transparent window, vice for job fixing, mechanism for lifting of job table and strong stand.

Technical Data

Tool area – 259.8 mm^2.

Cross head stroke - 150 mm.

Job holder - 100 mm opening X 50 mm depth X 100 mm width.

Tool feed motor - DC Servo type.

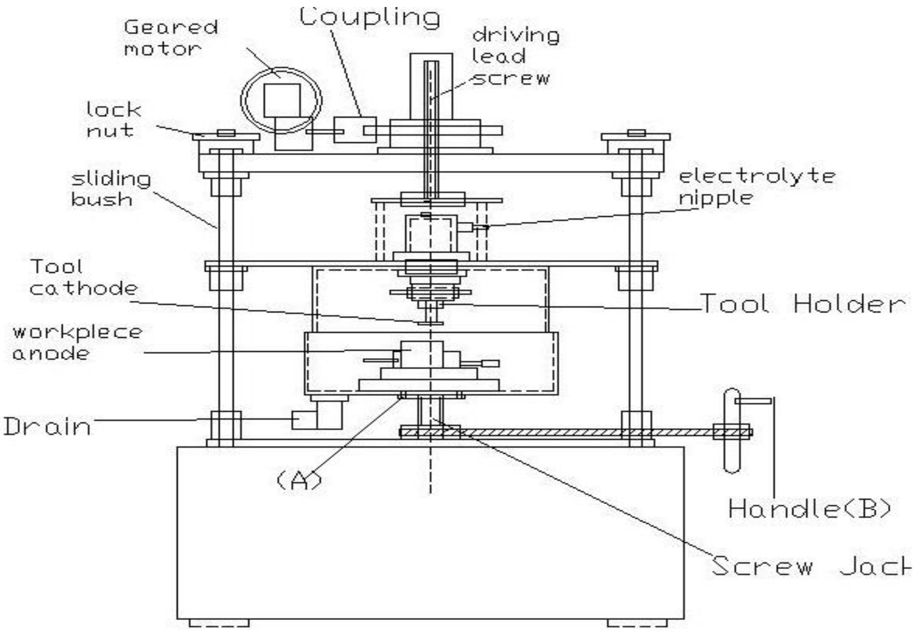


Figure 3.1 Schematic diagram of ECM[31]

Figure 3.2 : ECM set up

3.1.2 Control Panel

Through control panel we adjust the voltage (V), current (C), feed rate (F) and time (T) for duration of experiment. This is shown in fig 3.3.

Technical data

- ✓ Electrical Out Put Rating - 0-300 A. DC at any voltage from 0 - 20 V.
- ✓ Efficiency - Better than 80% at partial & full load condition.
- ✓ Operation Modes - Manual/Automatic.
- ✓ Tool Feed - 0.2 to 2 mm / min.
- ✓ Supply - 415 V +/- 10%, 3ϕ AC, 50 Hz.

Figure 3.3 : Control panel

3.1.3 Electrolyte Circulation system

The pumping of electrolyte is done from a tank. With the assistance of corrosion resistance pump, the tank is lined by corrosion resistant coating & is fed to the job. The spent electrolyte will return to the tank. The hydroxide sludge produced will settle at the base of the tank & can be drained out without difficulty. Governing of electrolyte supply is done by flow control valve.

Figure 3.4: Electrolyte Chamber

3.2 Tool design

Generally non reacting material such as Copper is used as tool in ECM. To determine a cathode shape which will machine a specified work piece shape was objective in study of tool design problem in ECM. Cathode material taken in this experiment is made up of copper. In this test copper is taken as cathode material as cathode. It is made up of copper rod of length 40 mm with hexagonal cross section at one end having length of each side equal to 10 mm, a through gap is made at the middle by a 3 mm boring tool made up of fast steel.

Chapter 4 : Experimental Work

4.1 Specifications of work piece materials

Work piece material: AISI 304 Stainless Steel

For this experimental investigation we have chosen AISI 304 Stainless steel as work piece. Work piece is having dimension of 100 X 60 mm and 5 mm in thickness. I have taken 2 pieces of AISI 304 material and carried out the experiment .In one work piece 15 cavities are done while in second workpiece 5 experiments were done. And the corresponding material removal rate is evaluated by measuring initial and final weight of work piece before and after the experiment.

Table 4.1: Structure varieties for AISI 304 mark stainless steel[31]

Grade		C	Si	P	S	Mn	Cr	Ni	N
304	Minimum	-	-	-	-	-	18.0	8.0	-
	Maximum	0.08	0.75	0.045	0.030	2.0	20.0	10.5	0.10

Table 4.2: Mechanical properties of AISI 304 grade stainless steel[33]

Grade	Tensile Strength (MPa) Minimum	Yield Strength 0.2% proof (MPa) Min	Elongation % (in 50 mm) min.	Hardness	
				Rockwell(B) Max.	Brinell(HB) Max
304	515	205	40	92	201

4.2 Selection of tool material

Figure 4.1: Tool

Copper is used as tool material because they are easily machined, they are conductive materials, and they will not corrode. It is made up of copper rod of length 40 mm with hexagonal cross section at one end having length of each side equal to 10 mm, a through gap is made at the middle by a 3 mm boring tool made up of fast steel.

4.3 Making of Brine Solution or Electrolyte

In Electrochemical Machining Process process the making of brine solution plays an essential role in material removal rate. Electrolyte is prepared by addition of common salt with water while maintaining the conductivity of water. So we have to take salt solution. In order to maintain the material removal rate correctly we have to maintain the conductivity through out the end of the experiment. For this experiment we have taken 100 gm of salt,125 gm of salt and 150 gm of salt sample in 1000 mL of water in room temperature

4.4 Mechanism of MRR

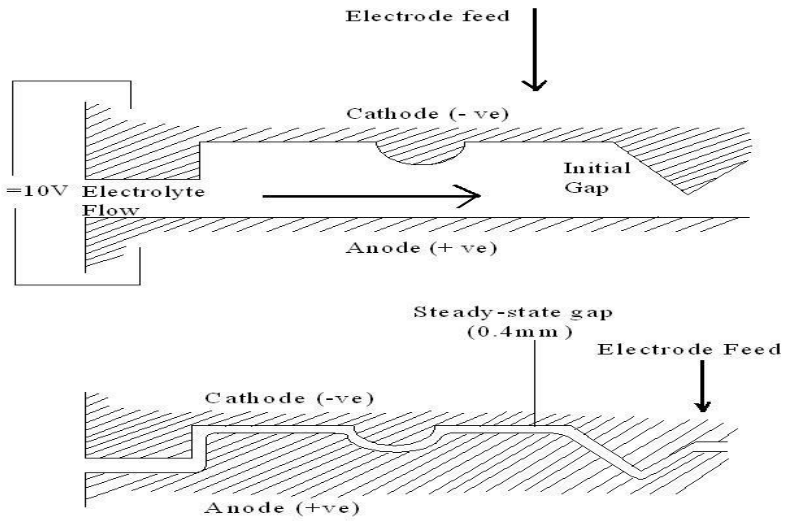


Figure 4.2 : Mechanism of MRR in ECM[33]

The working principle of ECM is schematically shown in figure 4.2. The workpiece and the tool are the anode and cathode respectively. In the electrolyte cell, a constant potential difference is applied across them.

The cathode or the tool is connected to the negative terminal of this power supply and anode is connected to the positive end of this power source. Inbetween the electrolyte is kept on flowing leaving a gap between workpiece and the tool. Tool can have different shape as per the requirement.The gap which was initially uneven, after electrolysis is taking place, the gap will come to be an uniform gap throughout and the process will continue further. This is basically the working principle in ECM. The gap will be maintained by the appropriate control system either for the tool advancement or the workpiece advancement at a particular rate. Through the gap the electrolyte is kept on flowing continuously which will keep connection between the power source , cathode and anode alive. At the same time it takes away the debris produced in this machining region which are nothing but the ions, metal ions. As the machining preceds there is a simultaneous movement of cathode towards anode to maintain this gap.

4.4.1 Calculation of MRR

$$MRR = \frac{Wbm - Wam}{\rho \times \text{time}} \quad \text{mm}^3/\text{min}$$

Where Wbm = Weight of workpiece before machining (in gram).

Wam = Weight of workpiece after machining (in gram).

t = Machining period = 10 min.

ρ = Density of AISI 304 stainless steel work piece = 8000 kg/m^3

4.5 Overcut

As the tool advances towards the workpiece during machining if the side faces of tool are not insulated, so the tool will start cutting in side also and the hole will become tapered.

4.5.1 Calculation of Overcut

Overcut is measured by the following formula

$$\text{Overcut} = \frac{d1 - d2}{2} \text{ mm}$$

Where d_1 = length of diagonal of cavity on workpiece

d_2= length of diagonal on tool

4.6 Response Surface Methodology (RSM)

Response Surface Methodology (RSM) is collection of mathematical and statistical methods for building experimental model and analysis of problems. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables) with a goal to find the correlation between the response and the variables. A Central Composite Design (CCD) predicts the performance characteristic at high degree of accuracy during experimentation. Therefore, RSM using CCD with three variables yield a total of 20 runs in three blocks, where the cardinal points used are; 8 cube points, 6 axial points and 6 centre points [Minitab16, 2011]. Electrolyte concentration, voltage and feed rate were the three experimental factors capable of influencing the process responses, namely, MRR, SR and OC. Hence, these factors were considered for exploration.

An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response. Equation for response y is given by

$$y = f(x_1, x_2) + e$$

The variables x_1 and x_2 are independent variables where the response y depends on them. The dependent variable y is a function of x_1, x_2, and the experimental error term, denoted as *e*. The error term e represents any measurement error on the response. If the response can be defined by a linear function of independent variables, then the approximating function is a first-order model. A first-order model with 2 independent variables can be expressed as

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon$$

If there is a curvature in the response surface, then a higher degree polynomial must be used. The approximating function with 2 variables is called a second-order model:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_{22}^2 + \beta_{12} x_1 x_2 + \varepsilon$$

where y : response value corresponding to x_1

x_1^2 - square terms of parameters

$x_1 x_2$ - interaction terms of parameters

$\beta_0 \beta_1 \beta_2$ - unknown regression coefficients

ε - error

Table 4.3: Machining parameters and their level

Machining parameter	Unit	Level		
		Level 1	Level 2	Level 3
Voltage (V)	volt	10	13.5	17
Feed rate (F)	mm/min	0.4	0.6	0.8
Concentration(C)	gm/lit	100	125	150

First of all it was checked how many factors are available for the experiment and then for this experiment three factors voltage (V), feed rate (F) and electrolyte concentration(C) were taken into the consideration.

4.7 Procedure of the experiment

Before starting the experiment measure the initial weight of the work piece using a precision electronic balance (least count 0.001 g) to calculate the MRR. After setting all the parameters in the control panel (like feed rate, voltage, current and time) and setting the work piece in the chamber, machining was started by using a copper electrode. The time of machining of the work piece at certain feed rate and voltage is being noted down. The values of surface roughness are measured by means of an portable type profilometer, Talysurf (Model: Surtronic 3+, Taylor Hobson). After measurement it is calculated by arithmetic mean of two data as the absolute value**.** Overcut is calculated after observation of machined surface under Tool makers microscope.

Figure 4.3: Work piece after machining.

4.8 Observation tables

Table 4.4: Experimental Layout (RSM Design Stainless steel AISI 304)

Std Order	Concentration (in gm/litre)	Voltage (volts)	Feed (mm/min)	MRR (mm^3/min)	Ra (µm)	Overcut (µm)
1	100	10	0.4	12.2500	2.22	0.9684
2	150	10	0.4	6.9000	2.20	0.4754
3	100	17	0.4	9.2250	2.52	0.0795
4	150	17	0.4	6.2000	2.72	0.0894
5	100	10	0.8	9.1875	2.18	0.0099
6	150	10	0.8	7.5000	1.34	0.0298
7	100	17	0.8	7.8700	3.64	0.3865
8	150	17	0.8	6.0800	3.22	0.5886
9	100	13.5	0.6	8.6500	1.70	0.5396
10	150	13.5	0.6	6.8500	0.94	0.5311
11	125	10	0.6	7.2700	1.42	0.5796
12	125	17	0.6	5.5800	2.46	0.5058
13	125	13.5	0.4	14.8700	2.64	0.2369
14	125	13.5	0.8	13.5600	3.24	0.2486
15	125	13.5	0.6	7.4500	2.44	0.4890
16	125	13.5	0.6	8.1300	2.24	0.4953
17	125	13.5	0.6	5.8980	2.18	0.5206
18	125	13.5	0.6	7.2400	2.86	0.4965
19	125	13.5	0.6	7.9200	2.32	0.5205
20	125	13.5	0.6	8.5400	2.84	0.5249

Chapter 5 : Results and Discussions

In this chapter, the responses such as Material Removal Rate (MRR), Surface Roughness (SR) and overcut (OC) are calculated from the observation tables, which were analysed and discussed.

5.1 Experimental analysis and discussions

5.1.1 Effect on Material removal rate: The machinability of ECM depends on the electrolyte concentration, feed rate and voltage. The influence of various machining parameters on MRR (means) are shown in figure 5.1. The MRR gradually decreases with increase in electrolyte concentration. MRR increases with increase in voltage in the range of 10 to 13.5 and then decreases. But MRR decreases with increases in feed rate in the range 0.4 to 0.6 and then increases.

Table 5.1 : Analysis of Variance for Means of MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	101.351	101.351	11.2612	6.50	0.004
Linear	3	28.039	28.039	9.3463	5.40	0.018
Square	3	69.574	69.574	23.1914	13.40	0.001
Interaction	3	3.738	3.738	1.2458	0.72	0.563
Lack-of-Fit	5	13.027	13.027	2.6054	3.04	0.124
Pure Error	5	4.286	4.286	0.8572		

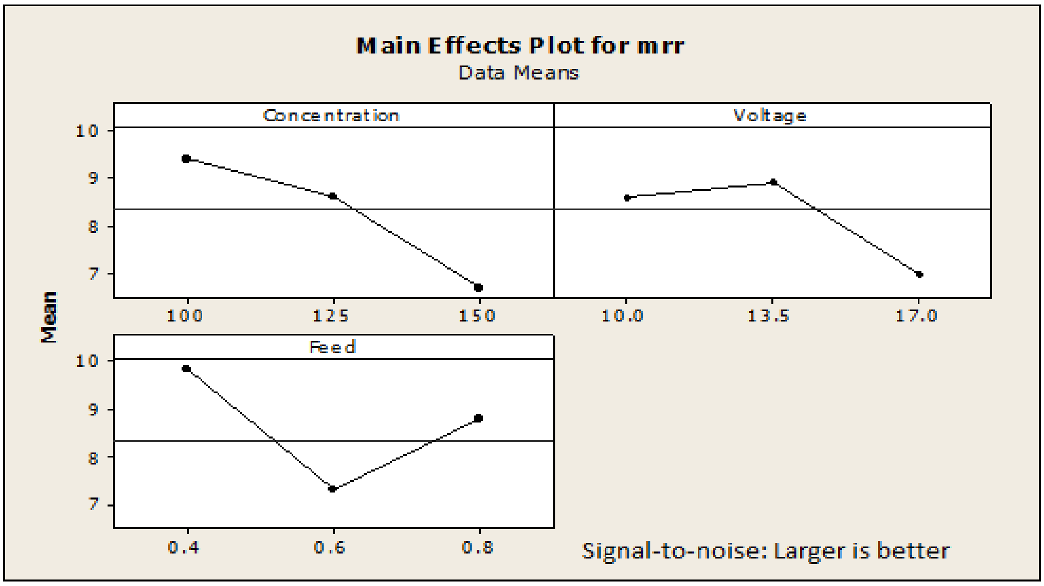


Figure 5.1 : Main effects of machining parameters on MRR (data means)

Table 5.2 Estimated Regression Coefficients for MRR

Term	Coef	SE Coef	T	P	Remarks
Constant	8.2830	0.4523	18.312	0.000	Significant
Concentration	-1.3652	0.4161	-3.281	0.008	Significant
Voltage	-0.8152	0.4161	-1.959	0.079	Non Significant
Feed	-0.5247	0.4161	-1.261	0.236	Non Significant
Concentration* Concentration	-1.6630	0.7935	-2.096	0.063	Non Significant
Voltage*Voltage	-2.9880	0.7935	-3.766	0.004	Significant
Feed*Feed	4.8020	0.7935	6.052	0.000	Significant
Concentration*Voltage	0.2778	0.4652	0.597	0.564	Non Significant
Concentration*Feed	0.6122	0.4652	1.316	0.218	Non Significant
Voltage*Feed	0.1234	0.4652	0.265	0.796	Non Significant
S= 1.31579		R-Sq =85.41%		R-Sq(adj)=72.28%	

Table 5.2 shows the Estimated Regression Coefficients for MRR. R^2 = 85.41 % indicates that the model is able to predict the response with good accuracy. The value of R^2 (adj) = 72.28%. The standard deviation of errors in the modelling, S= 1.31579, concentration (P=0.008) is significant. Squares V*V and F*F are significant while squares C*C and interactions C*V and C*F are insignificant.

The residual plot of MRR is shown in figure 5.2. Normal probability plot shows that the data are almost normally distributed and the variables are influencing the response. A standardized residue ranges from -2 and 2. Residuals versus fitted values indicate the variance is constant and a nonlinear relationship exists as well as no outliers exist in the data. Histogram proves the data are almost normally distributed it may be due to the fact that the number of points are very less. Residuals versus order of the data indicate that there are nearly systematic effects in the data.

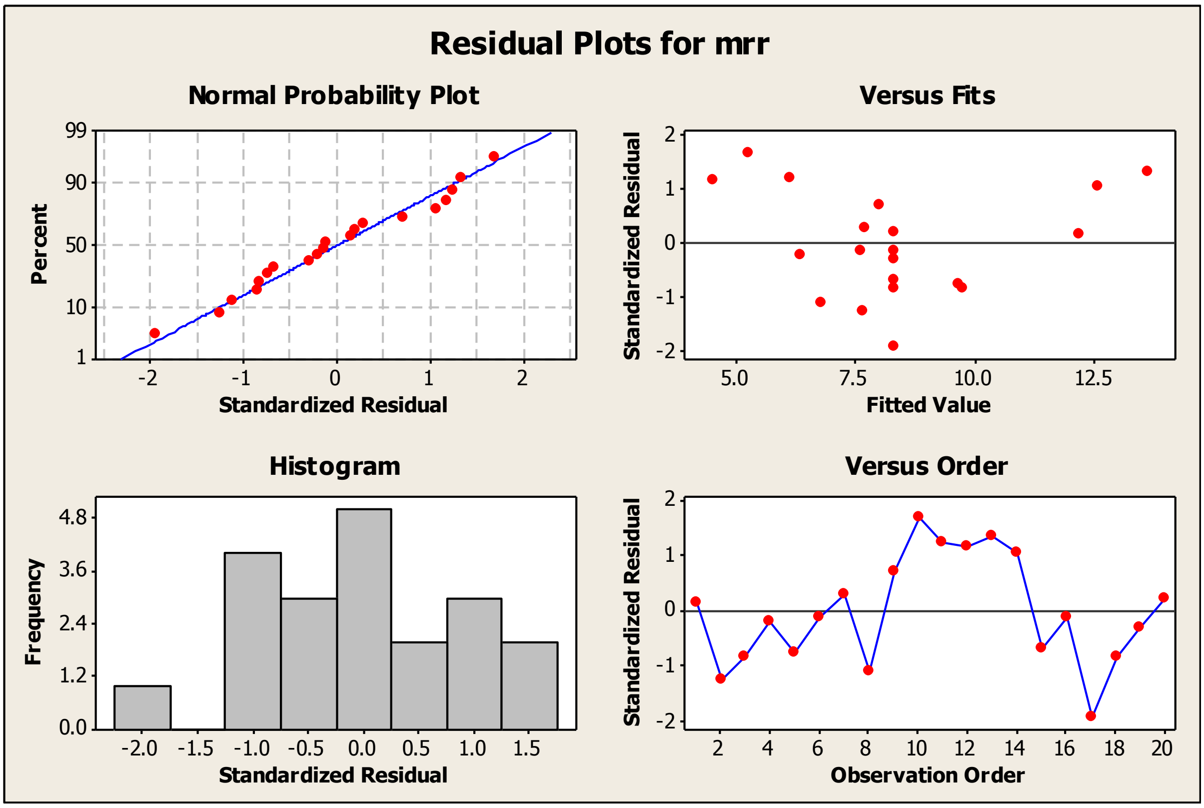


Figure 5.2 : Residual Plots for MRR

From RSM,empirical relationship between response and factors in coded forms are given as,

MRR = -7.01301 + 0.494256×Concentration + 0.243917×$(\text{Voltage})^2$ + 120.051×$(\text{Feed})^2$

5.1.2 Effect on Surface Roughness (SR): The influence of various machining parameters on SR (means) is shown in fig. 5.1. The SR slightly increases with increase in concentration in the range 100 to 125 and then decreases. SR increases with increase in voltage. But SR decreases with increases in feed in the range 0.4 to 0.6 and then increases.

Table 5.3 : Analysis of Variance for Means of SR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	7.06540	7.06540	0.78504	5.95	0.005
Linear	3	3.21680	3.21680	1.07227	8.13	0.005
Square	3	2.74440	2.74440	0.91480	6.94	0.008
Interaction	3	1.10420	1.10420	0.36807	2.79	0.095
Lack-of-Fit	5	0.86988	0.86988	0.17398	1.94	0.243
Pure Error	5	0.44880	0.44880	0.08976		

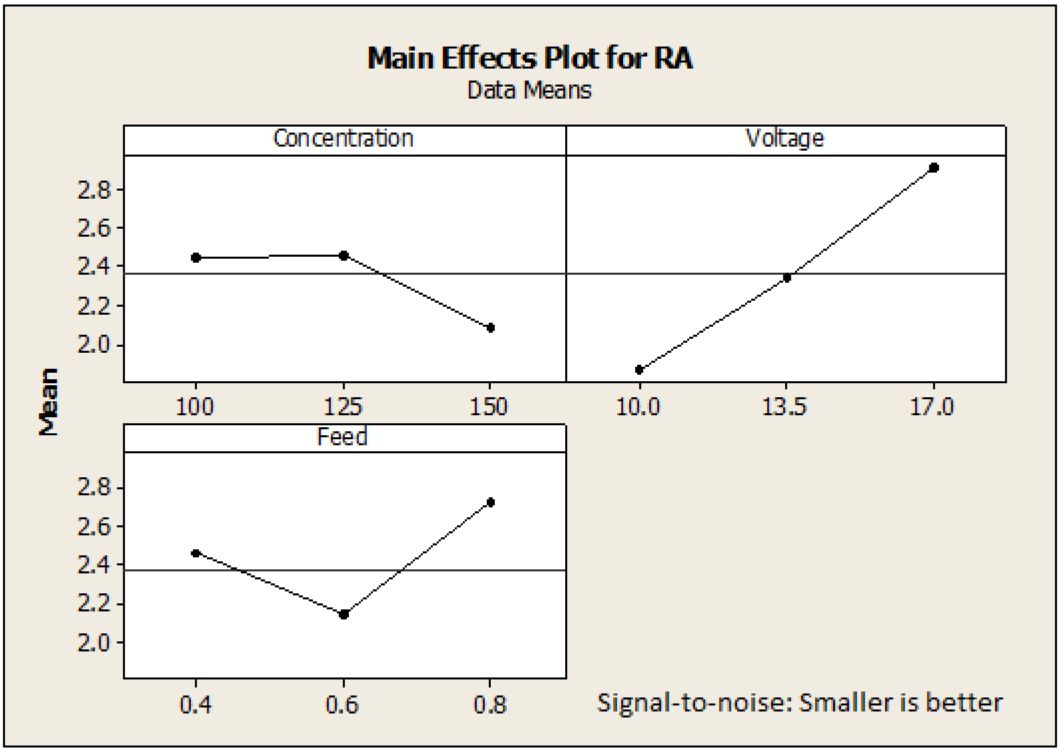


Figure 5.3 : Main effects of machining parameters on SR (data means)

Table 5.4: Estimated Regression Coefficients for SR

Term	Coef	SE Coef	T	P	Remarks
Constant	2.29600	0.1248	18.392	0.000	Significant
Concentration	-0.18400	0.1148	-1.602	0.140	Non Significant
Voltage	0.52000	0.1148	4.528	0.001	Significant
Feed	0.13200	0.1148	1.149	0.277	Non Significant
Concentration* Concentration	-0.70000	0.2190	-3.197	0.010	Significant
Voltage*Voltage	-0.08000	0.2190	-0.365	0.722	Non Significant
Feed*Feed	0.92000	0.2190	4.201	0.002	Significant
Concentration*Voltage	0.08000	0.1284	0.623	0.547	Non Significant
Concentration*Feed	-0.18000	0.1284	-1.402	0.191	Non Significant
Voltage*Feed	0.31500	0.1284	2.453	0.034	Significant
S= 0.363136	R-Sq=84.27%		R-Sq(adj)=70.12%		

The Estimated Regression Coefficients for SR is shown in table 5.4. R^2 = 84.27% indicates that the model is able to predict the response with good accuracy. Adjusted R^2 is a modified R^2 that has been adjusted for the number of terms in the model and its value is R^2 (adj) = 70.12%. The standard deviation of errors in the modelling, S = 0.363136, parameter voltage (P=0.001) is significant while concentration (P=0.140) and feed (P=0.277) is insignificant. Squares F*F, C*C and interactions V*F are significant while square V*V and interactions C*V, C*F are insignificant.

The residual plot of SR is shown in figure. 5.4. Normal probability plot shows that the data are not normally distributed and the variables are influencing the response. A standardized residue ranges from -2 and 2. Residuals versus fitted values indicate the variance is constant and a nonlinear relationship exists as well as no outliers exist in the data. Histogram proves the data are almost normally distributed it may be due to the fact that the number of points are very less. Residuals versus order of the data indicate that there are nearly systematic effects in the data.

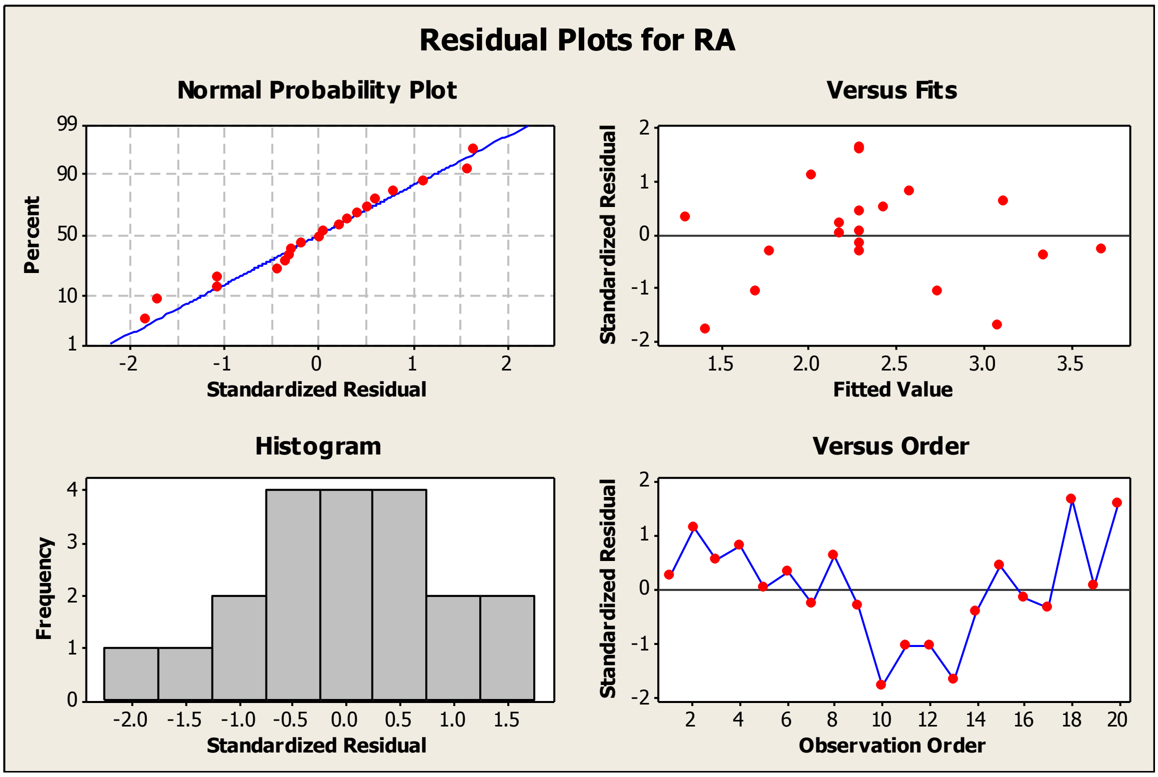


Figure 5.4 : Residual Plots for SR

From RSM,empirical relationship between response and factors in coded forms are given as,

SR = -7.10806 - 0.0593878 ×Voltage - 0.00112000×(Concetration)^2 + 23.0000×(Feed)^2 + 0.450000×Voltage×Feed

5.1.3 Effect on Overcut (OC): The influence of various machining parameters on overcut (means) are shown in figure 5.5. The overcut increases with increase in electrolyte concentration in the range 100 to 125 and then decreases. Overcut increases with increase in voltage in the range of 10 to 13.5 and then decreases. Overcut increases with increase in feed rate in the range 0.4 to 0.6 and then decreases.

Table 5.5 Analysis of Variance for Means of Overcut

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	1.17002	1.17002	0.130003	54.43	0.000
Linear	3	0.00622	0.00622	0.002073	0.87	0.489
Square	3	0.30117	0.30117	0.100389	42.03	0.000
Interaction	3	0.86264	0.86264	0.287547	120.39	0.000
Lack-of-Fit	5	0.01788	0.01788	0.003575	2.98	0.128
Pure Error	5	0.00601	0.00601	0.001202		

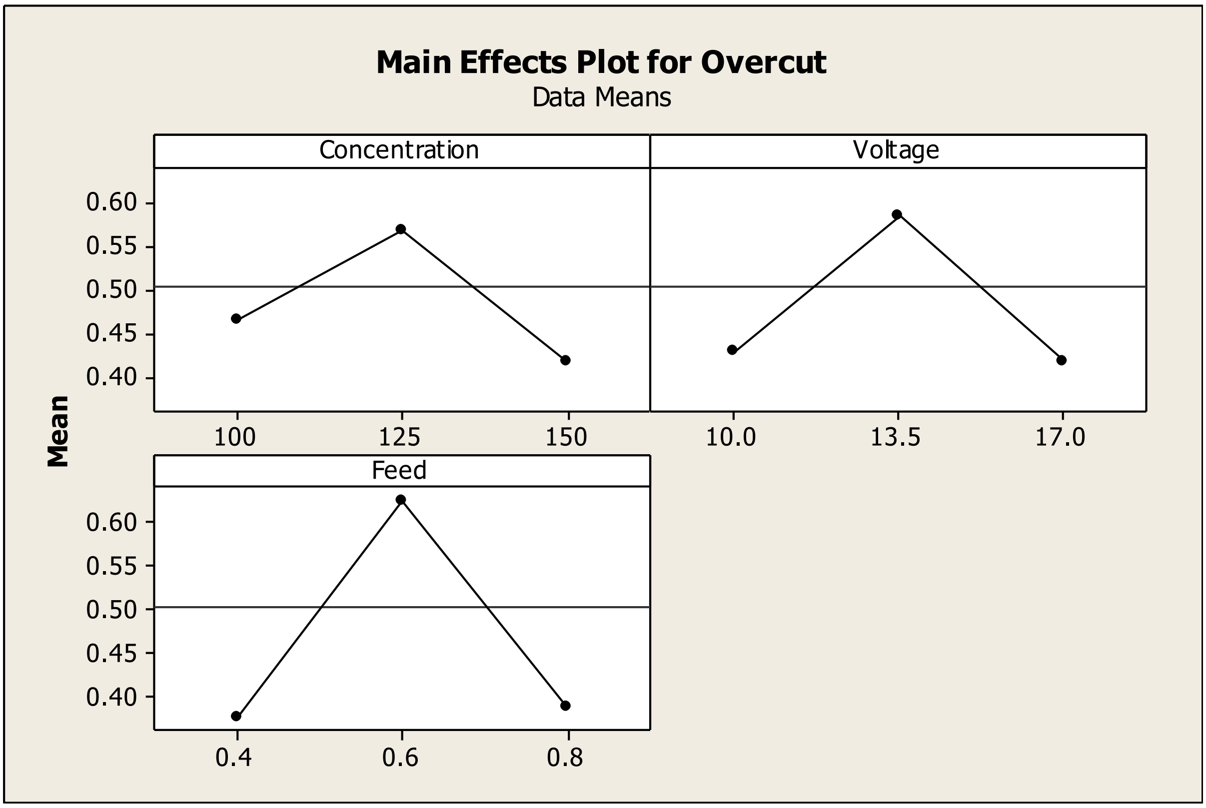


Figure 5.5 : Main effects of machining parameters on Overcut (data means)

Table 5.6 : Estimated Regression Coefficients for Overcut

Term	Coef	SE Coef	T	P	Remarks
Constant	3.93132	0.74087	5.306	0.000	Significant
Concentration	-0.02784	0.01228	-2.267	0.047	Significant
Voltage	-0.23460	0.07119	-3.296	0.008	Significant
Feed	0.25937	1.04177	0.249	0.808	Non Significant
Concentration* Concentration	0.00007	0.00005	1.512	0.162	Non Significant
Voltage*Voltage	-0.00347	0.00241	-1.444	0.179	Non Significant
Feed*Feed	-6.08761	0.73677	-8.263	0.000	Significant
Concentration*Voltage	0.00039	0.00020	1.953	0.079	Non Significant
Concentration*Feed	0.00646	0.00346	1.869	0.091	Non Significant
Voltage*Feed	0.46434	0.02468	18.811	0.000	Significant
S= 0.0488717	R-Sq=98.00%		R-Sq(adj)= 96.20%		

The Estimated Regression Coefficients for OC is shown in table 5.6. R^2 = 98.00 % indicates that the model is able to predict the response with good accuracy. Adjusted R^2 is a modified R^2 that has been adjusted for the number of terms in the model and its value is R^2 (adj) = 96.20%. The standard deviation of errors in the modelling, S= 0.0488717. Concentration (P=0.047) and voltage (P=0.008) are significant while feed (0.808) is non significant. Square F*F and interaction V*F are significant while squares like V*V, C*C and interactions V*C, C*F are insignificant.

Figure 5.6 shows the residual plot of OC. This layout is suitable to define whether the model meets the assumptions of the analysis. The data are almost normally distributed according to normal probability plot and the variables are influencing the response. A standardized residue ranges from -2 and 2. Residuals versus fitted values indicate the variance is constant and a nonlinear relationship exists as well as no outliers exist in the data. Histogram proves the data are almost normally distributed. It may be due to the fact that the number of points are very less. Residuals versus order of the data indicate that there are nearly systematic effects in the data.

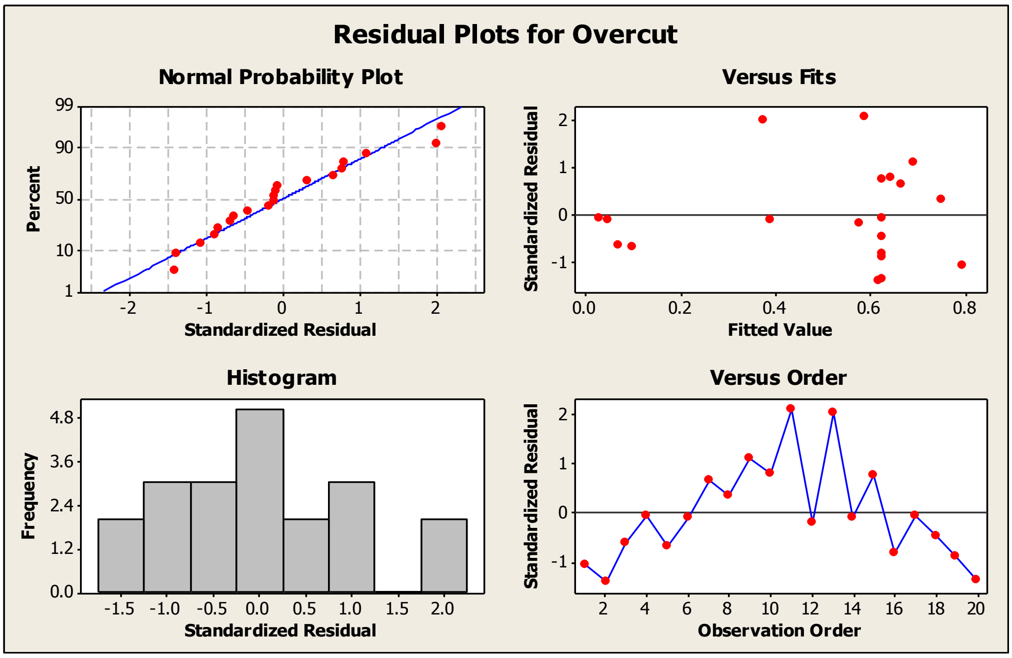


Figure 5.6 Residual Plots for Overcut

From RSM,empirical relationship between response and factors in coded forms are given as,

OC = 3.93132 -0.0278399×Concentration - 0.234603×Voltage - 6.08761×$(\text{Feed})^2$ + 0.464339×Voltage×Feed

5.1.4 Determination of optimum solution

By combining all the objectives we obtained a multi-objective optimization relation,

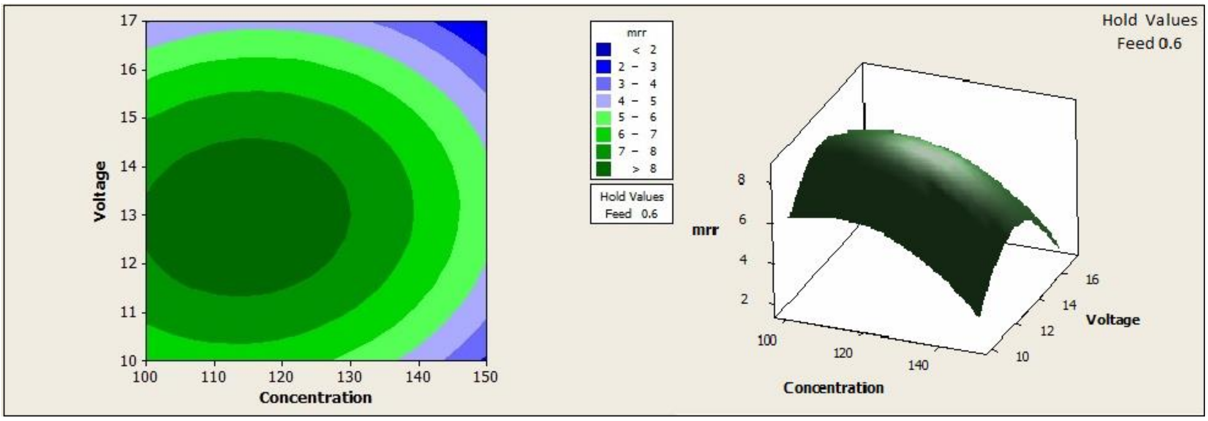
$$\text{Min}(Z_1) = w1\frac{Zoc}{OCmin} + w2\frac{Zsr}{SRmin} - w3\frac{Zmrr}{MRRmin}$$

The optimum condition for maximum MRR, minimum SR and min OC is electrolyte concentration 100gm/lit, voltage 17 volts and feed 0.6 mm/min.

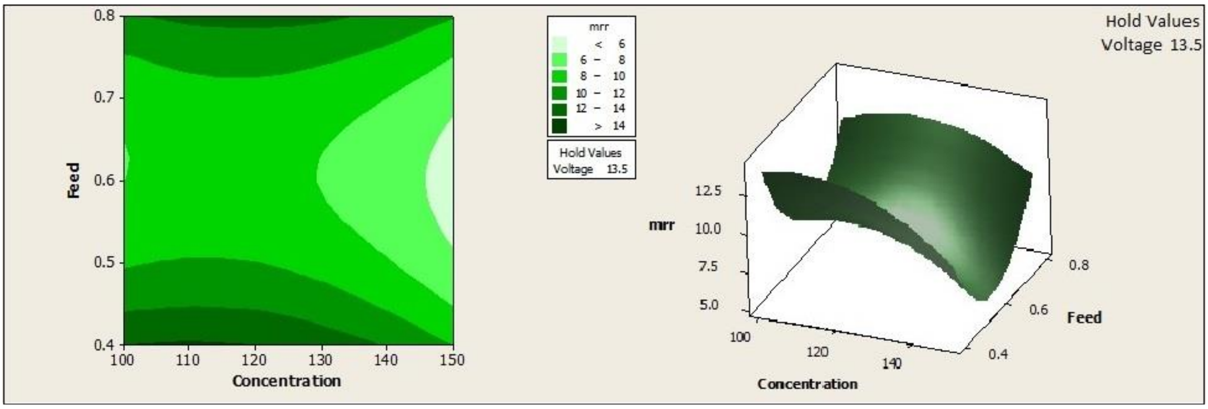
5.2 Contour and Surface Plot

5.2.1 Material Removal Rate (MRR): MRR increases with decrease in concentration. MRR initially increases and then decreases when voltage increases. MRR initially decreases and then increases when feed increases.

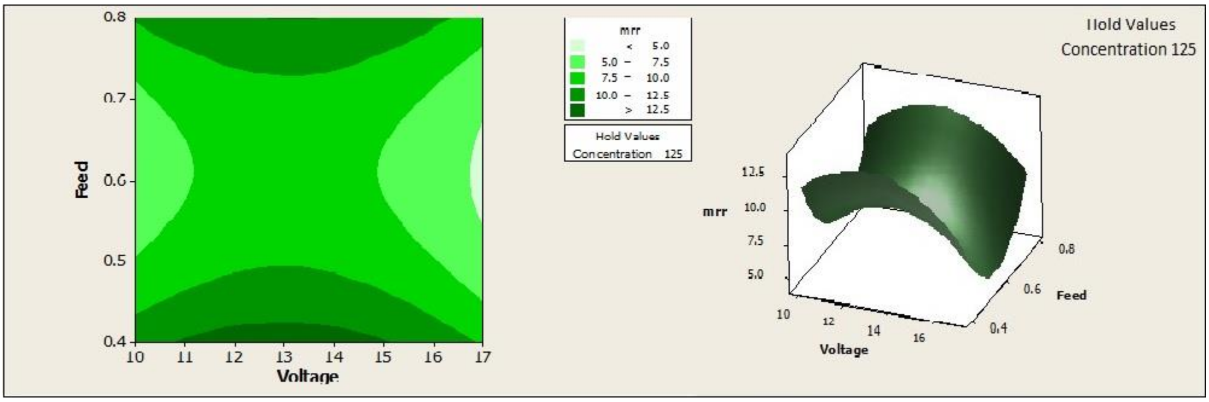
a. Concentration vs Voltage



b. Concentration vs feed

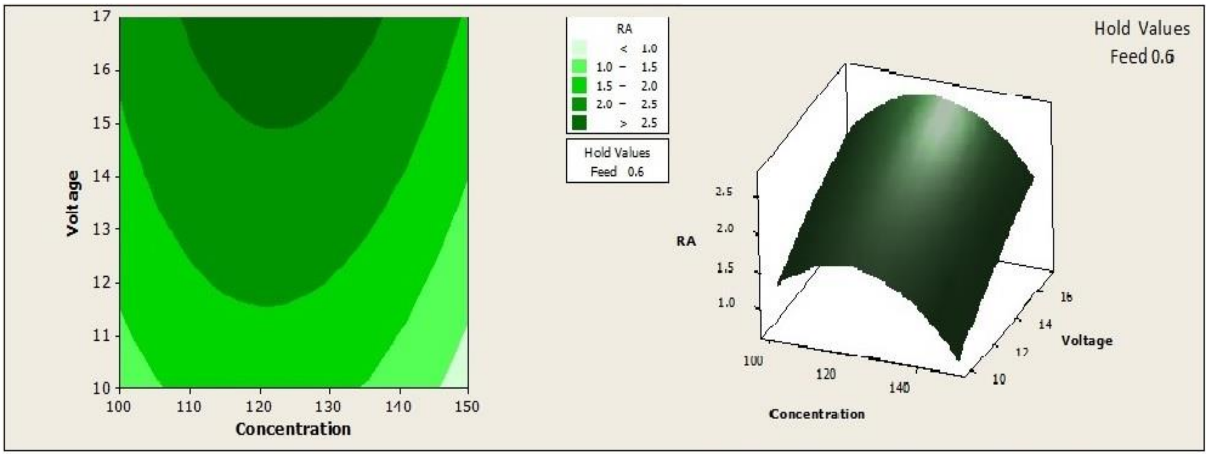


c. Voltage vs feed

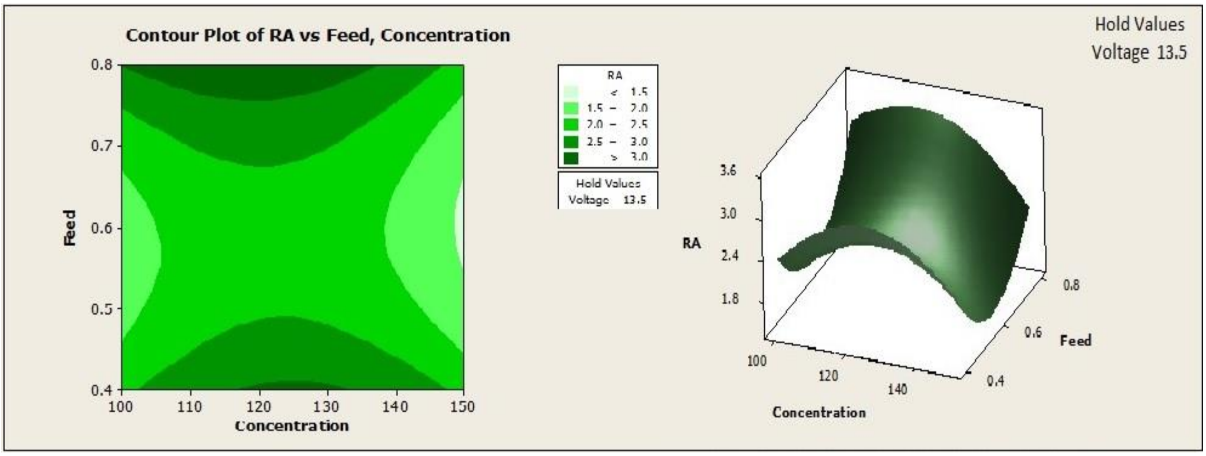


5.2.2 Surface Roughness: SR decreases with decrease in voltage. SR initially increases and then decreases when concentration increases. SR initially decreases and then increases when feed increases.

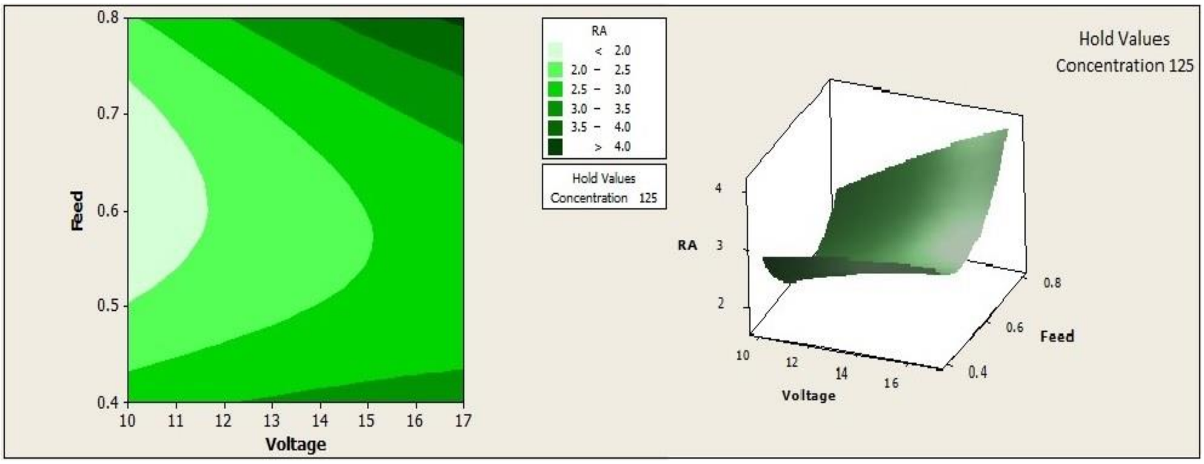
a. Concentration vs Voltage



b. Concentration vs feed

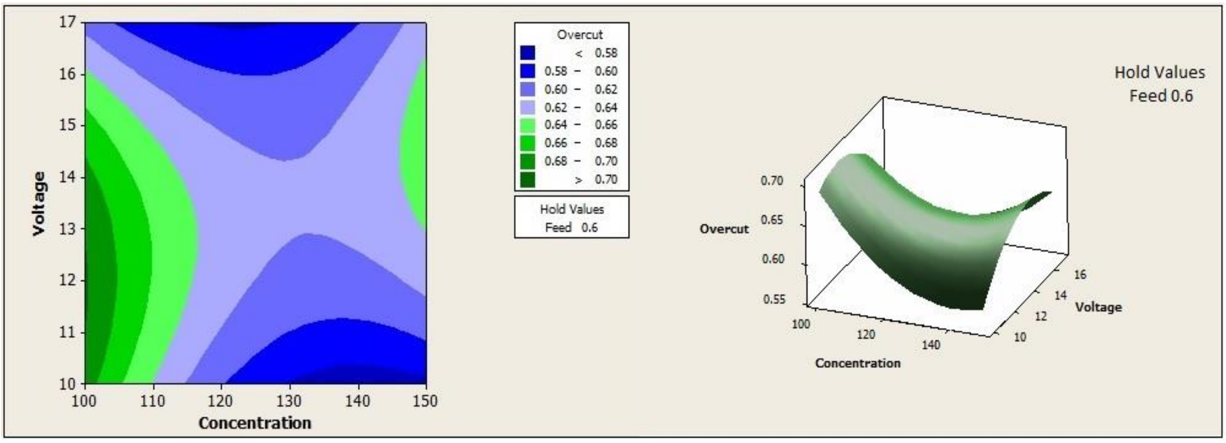


c. Voltage vs feed

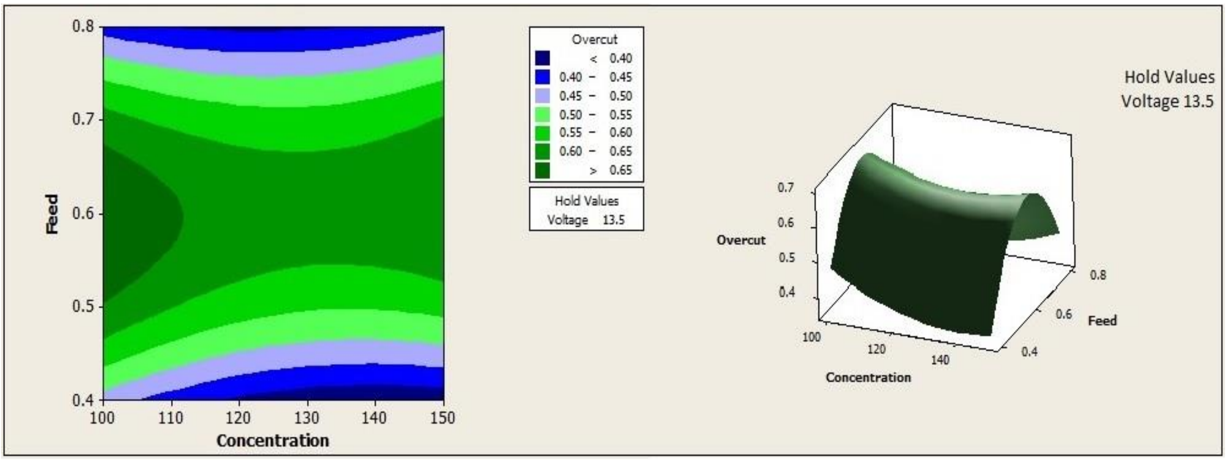


5.2.3 Overcut: OC increases with decrease in concentration. OC increases when voltage increases. OC initially increases and then decreases when feed increases.

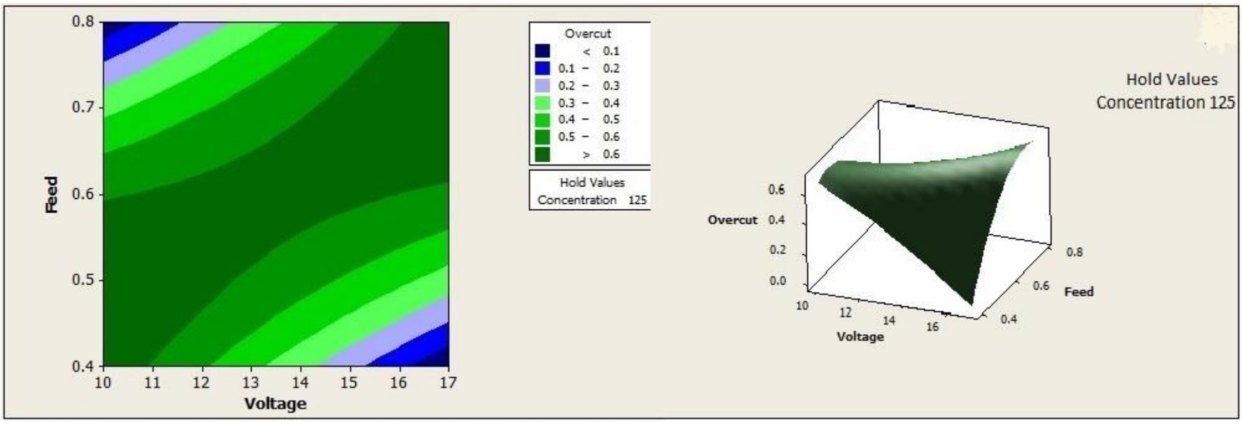
a. Concentration vs Voltage



b. Concentration vs feed



c. Voltage vs feed



Chapter 6 : Conclusion

In this investigational experiment on Electrochemical machining, study on the effect of machining responses material removal rate (MRR), surface roughness (SR) and overcut (OC) of the stainless steel AISI304 specimen using a Copper electrode have been investigated. The experiment was conducted under various machining parameters setting of voltage (V), feed (F) and electrolyte concentration(C). Experiments were conducted using RSM design which was performed by Minitab software and results were analysed and these responses were partially validated experimentally.

Concluded on the basis of RSM design :

(1) Parameters most affecting material removal rate are interaction feed*feed then interaction voltage*voltage and then concentration. MRR gradually decreases with increase in electrolyte concentration. MRR increases with increase in voltage in the range of 10 to 13.5 and then decreases. But MRR decreases with increase in feed rate in the range 0.4 to 0.6 and then increases. The optimum condition for maximum MRR is electrolyte concentration 100 gm/lit, voltage 13.5 volts and feed rate 0.6 mm/rate.

(2) Parameters affecting surface finish are voltage then interaction feed*feed and then interaction voltage*feed. SR increases with increase in voltage. The SR slightly increases with increase in concentration in the range 100 to 125 and then decreases. But SR decreases with increases in feed in the range 0.4 to 0.6 and then increases. The optimum condition for minimum surface roughness is electrolyte concentration 125 gm/lit, voltage 10 volts and feed 0.6mm/min.

(3) Parameters affecting overcut are interaction feed*feed and voltage*feed then voltage and then electrolyte concentration. OC increases with increase in electrolyte concentration in the range 100 to 125 and then decreases. Overcut increases with increase in voltage in the range

of 10 to 13.5 and then decreases. Overcut increases with increase in feed rate in the range 0.4 to 0.6 and then decreases. The optimum condition for minimum overcut is electrolyte concentration 150 gm/lit, voltage 17volts and feed rate 0.4 mm/min.

(4) The optimum condition for maximum MRR, minimum SR and min OC is electrolyte concentration 100gm/lit, voltage 17 volts and feed 0.6 mm/min. Overall response for maximum MRR, minimum SR and OC was most influenced by feed rate, then voltage and then electrolyte concentration.

Chapter 7 : Appendix

7.1 Talysurf profilometer

The surface roughness values are measured by means of an apparatus portable type profilometer, Talysurf (Model: Surtronic 3+, Taylor Hobson) shown in figure 7.1. It has been taken readings at three points and taken average value of these three readings for SR.

Figure 7.1: Talysurf (Model: Surtronic 3+, Taylor Hobson)[31]

7.2 Weight balance specification

The calculation of material removal rate has been done by using electronic sense of balance weight machine as displayed in figure 7.2. For each weight measurement first soak the work piece from paper or cloth to prevent from extra weight measurement. This machine having capability measure weight up to 300 g and accurateness is 0.001 g.

Figure 7.2: Digital weight balance machine (SHINKO DENSHI Co. LTD, JAPAN, Model: DJ 300S)[31]

7.3 Tool maker's microscope

The calculation of overcut has been done by using tool maker's microscope as displayed in figure 7.3.It is a instrument for measurements in thread inspection, gauges-tempelate checking, forming tools, verification of tool angles.A digital micrometer of least count 0.001 mm and LED lights is provided with.

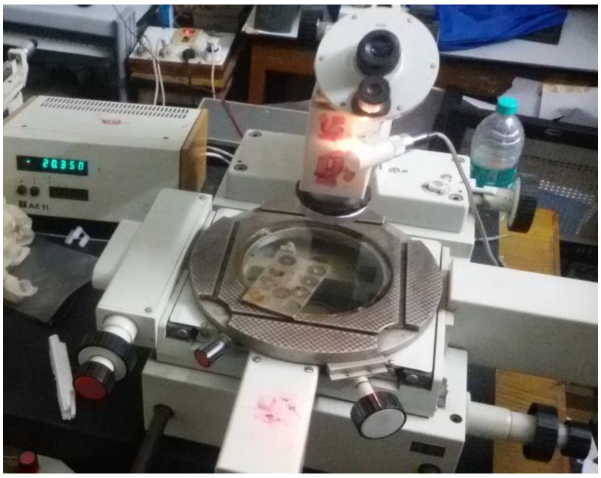


Figure 7.3 : Tool makers microscope

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